Radiological Dose Assessment

CHAPTER 7

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Introduction

Lawrence Livermore National Laboratory (LLNL) assesses potential radiological doses to biota, off-site individuals, and the population residing within 80 km of either the Livermore site or Site 300. These potential doses are calculated to determine the impact of LLNL operations, if any, on the general public and the environment, and to demonstrate compliance with regulatory standards set by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

Releases of radioactive material to air are the major source of public radiological exposure from LLNL operations, and radiological monitoring of stack air effluent and ambient air (Chapter 4) represents a significant monitoring effort. In addition to ambient air and stack monitoring there is monitoring of radioactivity in a variety of media including soil, sediment, vegetation, wine and measured environmental gamma radiation (Chapter 6). Monitoring at LLNL also includes the sampling of wastewaters, storm water and groundwater as well as rainfall and local surface water (Chapter 5). Releases to these water systems are not sources of direct exposures to the public because they are not directly consumed.

Measurements of radiological releases to air and modeling the dispersion of the released radionuclides determine LLNL's dose to the public. Because LLNL is a DOE facility, it is subject to the requirements of Title 40 of the Code of Federal Regulations (CFR) Part 61 Subpart H, the National Emissions of Hazardous Air Pollutants (NESHAPs). LLNL uses the EPA Clean Air Act Assessment Package-1988 (CAP88-PC) computer model in

demonstrating site compliance with NESHAPs regulations. This dose code evaluates the four principal exposure pathways: ingestion, inhalation, air immersion, and irradiation by contaminated ground surface.

The major radionuclides measured by LLNL in 2005 that contribute to individual and collective dose were tritium at the Livermore site and three uranium isotopes (uranium-234, uranium-235, and uranium-238) at Site 300. All radionuclides measured at the Livermore site and Site 300 were used to assess dose to biota.

This chapter summarizes detailed radiological dose determinations and identifies trends over time while placing them in perspective with natural background and other sources of radiation exposure.

Releases of Radioactivity from LLNL Operations

Radiological releases to air are estimated by three principal means: continuous monitoring of stack effluent at selected facilities (described in Chapter 4); routine surveillance ambient air monitoring for radioactive particles and gases, both on and off LLNL property (also described in Chapter 4); and radioactive material usage inventories. Of these three approaches, stack monitoring provides the most definitive characterization. Beginning in 2003, the extent of reliance on usage inventories declined in favor of increased utilization of ambient air monitoring data (see the "Compliance Demonstration for Minor Sources" section below).

Radiation Protection Standards

The release of radionuclides from operations at LLNL and the resultant radiological impact to the public are regulated by both the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

The primary DOE radiation standards for protection of the public are 1 millisievert per year (1 mSv/y) (which equals 100 millirem per year [100 mrem/y]) whole-body effective dose equivalent (EDE) for prolonged exposure of a maximally exposed individual in an uncontrolled area and 5 mSv/y (500 mrem/y) EDE for occasional exposure of this individual. (EDEs and other technical terms are discussed in *Supplementary Topics on Radiological Dose* [available on report CD] and defined in the glossary of this report.) These limits pertain to the sum of the EDE from external radiation and the committed 50-year EDE from radioactive materials ingested or inhaled during a particular year that may remain in the body for many years.

The EPA's radiation dose standard for members of the public limits the EDE to 100 μSv/y (10 mrem/y) for air emissions. EPA regulations specify not only the allowed levels, but also the approved methods by which airborne emissions and their impacts must be evaluated. With respect to all new or modified projects, NESHAPs compliance obligations define the requirements to install continuous air effluent monitoring and to obtain EPA approval before the startup of new operations. NESHAPs regulations require that any operation with the potential to produce an annual average off-site dose greater than or equal to 1 μSv/y (0.1 mrem/y), taking full credit for emission-abatement devices such as high-efficiency particulate air (HEPA) filters, must obtain EPA approval prior to the startup of operations. This same calculation, but without taking any credit for emission abatement devices, determines whether or not continuous monitoring of emissions to air from a project is required. These requirements are spelled out in LLNL's *Environment, Safety, and Health (ES&H) Manual*, Document 31.2, "Radiological Air Quality Compliance."

Air Dispersion and Dose Models

Computational models are needed to describe the transport and dispersion in air of contaminants and the doses to exposed persons via all pathways. CAP88-PC is the DOE and EPA mandated computer code used by LLNL to compute radiological individual or collective (i.e., population) dose resulting from radionuclide emissions to air. This code operates on a personal computer and is relatively easy to use and understand.

CAP88-PC uses a modified Gaussian plume equation to estimate the average dispersion of radionuclides released from up to six collocated sources (Parks 1992). Input parameters used in the model include radionuclide type, emission rate in curies per year, and stack parameters, such as stack height, inside diameter and exit velocity. A site-specific wind parameter file is prepared annually from meteorological data collected by LLNL. The mathematical models and equations used in CAP88-PC are described in *User's Guide for CAP88-PC, Version 1.0* (Parks 1992).

Calculated doses include the four principal exposure pathways: internal exposures from inhalation of air and ingestion of foodstuff and drinking water (only for tritium), and external exposures through irradiation from contaminated ground and immersion in contaminated air. Dose is calculated as a function of radionuclide, pathway, spatial location, and body organ.

In addition, CAP88-PC provides the flexibility to adjust agricultural parameters (e.g., numbers of milk cows per km^2) and the fractions of contaminated foods ingested. For the 2005 evaluation, LLNL took advantage of this capability and used updated assumptions for agricultural and food

source parameters for CAP88-PC (see Larson et al. 2006). This is the second year these updated assumptions have been used. Furthermore, an improved tritium model (NEWTRIT; Peterson and Davis 2002) that uses air concentrations predicted by CAP88-PC to address the dose from releases of HT and the dose from organically bound tritium was again employed to compare with the tritium model in CAP88-PC.

Identification of Key Receptors

Dose is assessed for two types of receptors. First is the dose to the site-wide maximally exposed individual (SW-MEI; defined below) member of the public. Second is the collective or "population" dose received by people residing within 80 km of either of the two LLNL sites.

The SW-MEI is defined as the hypothetical member of the public at a single, publicly accessible location who receives the greatest LLNL-induced EDE from all sources at a site. For LLNL to comply with NESHAPs regulations, the LLNL SW-MEI must not receive an EDE as great or greater than 100 μSv/y (10 mrem/y) from releases of radioactive material to air. Public facilities that could be the location of the SW-MEI include schools, churches, businesses, and residences. This hypothetical person is assumed to remain at one location 24 hours per day, 365 days per year, continuously breathing air having the predicted or observed radionuclide concentration, and consuming a specified fraction of food and drinking water[1] that is affected by the same predicted or observed air concentration caused by releases of radioactivity from the site. Thus, the SW-MEI dose is not received by any actual individual and is a conservative estimate of the highest possible dose that may be received by any member of the public.

At the Livermore site, the SW-MEI in 2005 was located at the UNCLE Credit Union, about 10 m outside the controlled eastern perimeter of the site. This location lies 957 m from the Tritium Facility (Building 331), in an east-northeast direction (the typical prevailing wind direction). At Site 300, the SW-MEI occupied a position on the south-central boundary of the site bordering the Carnegie State Vehicular Recreation Area, 3170 m south-southeast of the firing table at Building 851. These SW-MEI locations are depicted in **Figure 7-1**.

[1] This is calculated for tritium only.

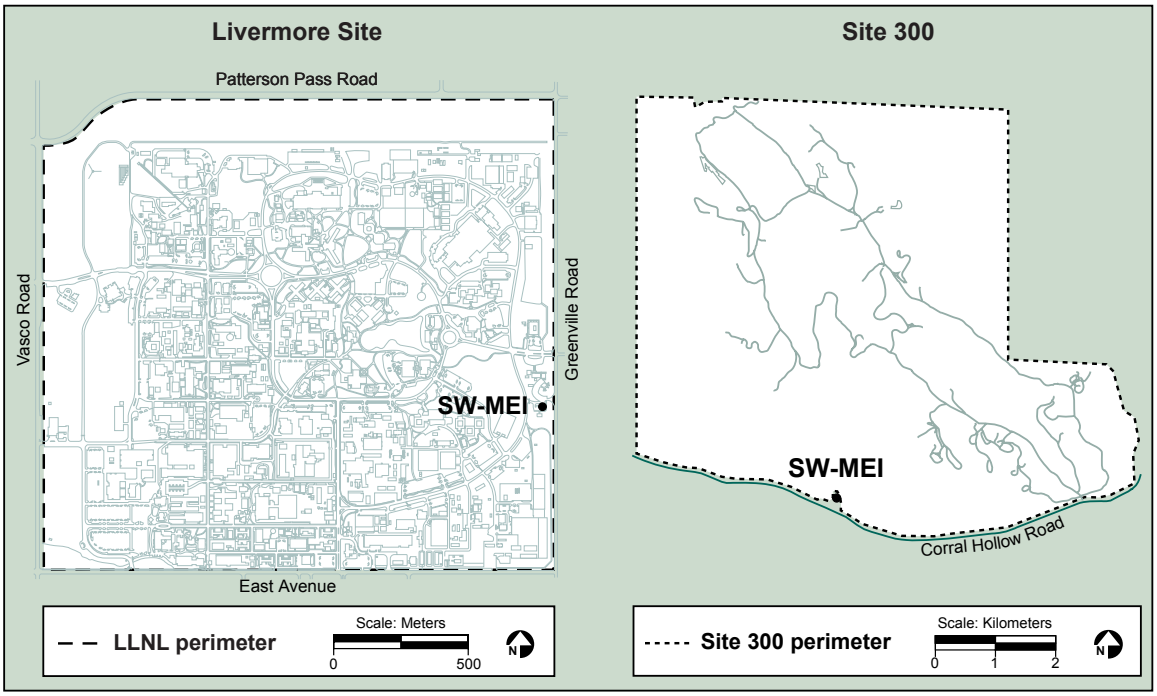

Figure 7-1. Location of the site-wide maximally exposed individual (SW-MEI) at the Livermore site and Site 300, 2005

Results of 2005 Radiological Dose Assessment

This section summarizes the doses to the most exposed public individuals from LLNL operations in 2005, shows the temporal trends compared with previous years, presents the potential doses to the populations residing within 80 km of either the Livermore site or Site 300, and places the potential doses from LLNL operations in perspective with doses from other sources.

Total Dose to Site-Wide Maximally Exposed Individuals

The total dose to the SW-MEI from Livermore site operations in 2005 was 0.065 μSv/y (0.0065 mrem/y). Of this, the dose attributed to diffuse emissions (area sources) totaled 0.038 μSv (0.0038 mrem) or 59%; the dose due to point sources was 0.027 μSv (0.0027 mrem) or 41% of the total. The point source dose includes Tritium Facility elemental tritium gas (HT) emissions modeled as tritiated water (HTO), as directed by EPA Region IX. Using NEWTRIT rather than CAP88-PC to calculate the dose for tritium emissions reduced the tritium component of the total dose from 0.059 μSv (0.0059 mrem) to 0.052 μSv (0.0052 mrem).

The total dose to the Site 300 SW-MEI from operations in 2005 was 0.18 µSv (0.018 mrem). Point source emissions from firing table explosives experiments totaled 0.088µSv (0.0088 mrem) accounting for 48% of the dose, while 0.094 µSv (0.0094 mrem), or about 52%, was contributed by diffuse emission sources.

Table 7-1 shows the facilities or sources that accounted for nearly 100% of the dose to the SW-MEI for the Livermore site and Site 300 in 2005. Although LLNL has nearly 150 sources with potential for releasing radioactive material to air according to NESHAPs prescriptions, most are very minor. Nearly the entire radiological dose to the public each year from LLNL operations comes from no more than six sources. In April 2003, EPA granted LLNL permission to use surveillance monitoring in place of inventory-based modeling to account for dose contributions from the numerous minor sources. This procedure was implemented for the third time in assessing 2005 operations (see also *LLNL NESHAPs 2005 Annual Report* [Larson et al. 2006]).

Table 7-1. List of facilities or sources whose combined emissions accounted for nearly 100% of the SW-MEI doses for the Livermore site and Site 300 in 2005

Facility (source category)	CAP88-PC dose (µSv/y)[a]	CAP88-PC percentage contribution to total dose
Livermore site		
Building 331 stacks (point source)	0.026[b]	40
Building 612 Yard (diffuse source)	0.020[b]	31
Building 331 outside (diffuse source)	0.012[b]	18
Southeast Quadrant soil resuspension (diffuse source)	0.0061	9
Site 300		
Soil resuspension (diffuse source)	0.094	52
Building 851 Firing Table (point source)	0.088[c]	48

a 1 µSv = 0.1 mrem

b When LLNL's NEWTRIT model is used in place of CAP88-PC's default tritium model, the dose for the Building 331 stacks is reduced to approximately 86% of the value shown, and doses for the Building 612 Yard and Building 331 outside are reduced to 89% of the values shown.

c The Building 851 Firing Table had fewer explosive experiments in 2005 than in previous years.

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 91% of the Livermore site's calculated dose. At Site 300, practically the entire calculated dose was due to the isotopes uranium-238, uranium-235, and uranium-234 from depleted uranium.

Regarding pathways of exposure, the relative significance of inhalation and ingestion depends on the assumptions made about the origin of food consumed and the predominant radionuclide contributing to dose. For individual doses calculated for tritium, the ingestion dose accounts for slightly more than the inhalation dose, approximately 53% and 47%, respectively. For uranium, the inhalation pathway dominates: 97% by the inhalation pathway versus 3% via ingestion. LLNL doses from air immersion and ground irradiation are negligible for both tritium and uranium.

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last 15 years are shown in **Table 7-2**. The general pattern, particularly over the last decade, shows year-to-year fluctuations around a low dose level, staying at or below about 1% of the federal standard. The SW-MEI dose estimates are intentionally conservative, predicting potential doses that are higher than actually would be experienced by any member of the public.

Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides to the atmosphere at the Livermore site or Site 300 in 2005.

Collective Dose

Collective dose for both LLNL sites was calculated out to a distance of 80 km in all directions from the site centers using CAP88-PC. Population centers affected by LLNL emissions include the nearby communities of Livermore and Tracy; the more distant metropolitan areas of Oakland, San Francisco, and San Jose; and the San Joaquin Valley communities of Modesto and Stockton. Within the 80 km outer distance specified by DOE, there are 7.1 million residents included for the Livermore site collective dose determination, and 6.2 million for Site 300. Population data files (distribution of population with distance and direction) used for the present report are based on the LandScan Global Population 2001 Database (Dobson et al. 2000).

The CAP88-PC result for potential collective dose attributed to 2005 Livermore site operations was 0.0117 person-Sv (1.17 person-rem); the corresponding collective EDE from Site 300 operations was 0.0171 person-Sv (1.71 person-rem). These values are both within the normal range of variation seen from year to year.

Table 7-2. Doses (μSv/y)[a] calculated for the sitewide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2005

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
2005	0.065[b]	0.027[b]	0.038
2004	0.079[b]	0.021[b]	0.058
2003	0.44[b]	0.24[b]	0.20
2002	0.23[b]	0.10[b]	0.13
2001	0.17[b]	0.057[b]	0.11
2000	0.38[b]	0.17[b]	0.21
1999	1.2[b]	0.94[b]	0.28
1998	0.55[b]	0.31[b]	0.24
1997	0.97	0.78	0.19
1996	0.93	0.48	0.45
1995	0.41	0.19	0.22
1994	0.65	0.42	0.23
1993	0.66	0.40	0.26
1992	0.79	0.69	0.10
1991	2.34	—[c]	—[c]
1990	2.40	—[c]	—[c]
Site 300			
2005	0.18	0.088	0.094
2004	0.26	0.25	0.0086
2003	0.17	0.17	0.0034
2002	0.21	0.18	0.033
2001	0.54	0.50	0.037
2000	0.19	0.15	0.037
1999	0.35	0.34	0.012
1998	0.24	0.19	0.053
1997	0.20	0.11	0.088
1996	0.33	0.33	0.0045
1995	0.23	0.20	0.03
1994	0.81	0.49	0.32
1993	0.37	0.11	0.26
1992	0.21	0.21	—[d]
1991	0.44	0.44	—[d]
1990	0.57	0.57	—[d]

a 1 μSv = 0.1 mrem
b The dose includes HT emissions modeled as HTO as directed by EPA Region IX.
c Diffuse source doses were not calculated for the Livermore site for 1990 and 1991.
d No diffuse emissions were evaluated at Site 300 before 1993.

Although collective doses from LLNL operations are tiny compared with doses from natural background radiation, they may be high compared with other DOE facilities due to large populations within 80 km of the sites. However, a large dose to a small number of people is not equivalent to a small dose to many people, even though the collective dose may be the same. Given that the population centers potentially affected by LLNL operations are distant from both the Livermore site and Site 300, the collective doses from LLNL operations are better described by breaking them down into categories of dose received by individuals in the population affected. The breakdown (or disaggregation) of collective dose by the level of the individual dose in **Table 7-3** demonstrates that about 94% of the population receives less than 0.01 µSv/y (1 µrem/y).

Table 7-3. Collective dose broken down by level of individual doses, 2005

Individual dose range (µSv/y) [a]	Collective dose (person-Sv/y)[b]	Percent total collective dose
Livermore site		
0.01 to 0.1	0.0000517	0.444%
0.001 to 0.01	0.00716	61.0%
0.0001 to 0.001	0.00339	28.9%
0.00001 to 0.0001	0.00114	9.71%
Total[c]	0.0117	100%
Site 300[d]		
0.01 to 0.1	0.00107	6.25%
0.001 to 0.01	0.0106	62.0%
0.0001 to 0.001	0.00507	29.6%
0.00001 to 0.0001	0.000336	1.96%
0.00000001 to 0.00001	0.0000334	0.195%
Total	0.0171	100%

a 1 µSv = 0.1 mrem
b 1 person-Sv = 100 person-rem
c An additional 0.05% of the population received a dose less than 1×10^{-5} µSv.
d Dose from Building 851 Firing Table and Building 801A.

Doses to the Public Placed in Perspective

As a frame of reference to gauge the size of these LLNL doses, **Table 7-4** compares them to average doses received in the United States from exposure to natural background radiation and other sources. Collective doses from LLNL operations in 2005 are about 700,000 times smaller than ones from natural background radiation. The estimated maximum potential doses to

individual members of the public from operations at the two LLNL sites (combined) in 2005 are nearly 12,000 times smaller than ones received from background radiation in the natural environment.

Table 7-4. Comparison of background (natural and man-made) and LLNL radiation doses, 2005

Location/source	Individual dose[a] (μSv) [c]	Collective dose[b] (person-Sv) [d]
Livermore site sources		
Atmospheric emissions	0.065	0.0117
Site 300 sources		
Atmospheric emissions	0.18	0.0171
Other sources[e]		
Natural radioactivity[f,g]		
Cosmic radiation	300	2,130
Terrestrial radiation	300	2,130
Internal (food consumption)	400	2,840
Radon	2,000	14,200
Medical radiation (diagnostic procedures)[f]	530	3,760
Weapons test fallout[f]	10	71
Nuclear fuel cycle	4	28

a For LLNL sources, this dose represents that experienced by the SW-MEI.
b The collective dose is the combined dose for all individuals residing within an 80-km radius of LLNL (approximately 7.1 million people for the Livermore site and 6.2 million for Site 300), calculated with respect to distance and direction from each site. The Livermore site population estimate of 7.1 million people was used to calculate the collective doses for "Other sources".
c 1 μSv = 0.1 mrem
d 1 person-Sv = 100 person-rem
e From National Council on Radiation Protection and Measurements (NCRP 1987a,b)
f These values vary with location.
g This dose is an average over the U.S. population.

Special Topics on Dose Assessment

Compliance Demonstration for Minor Sources

From 1991 through 2002, LLNL demonstrated compliance for minor sources through a labor-intensive inventory and modeling process. The dose consequences to the public for these sources were 8 to 20 orders of magnitude below the regulatory standard of 100 μSv/y (10 mrem/y) and did not justify the level of effort expended in accounting for them. To better allocate resources, LLNL made a request to EPA, pursuant to the NESHAPs regulations, to use existing ambient air monitoring to demonstrate compliance for minor sources. This request was made in March 2003 and

granted by EPA in April 2003. This report marks the third year that LLNL is demonstrating NESHAPs compliance for minor sources by comparing measured ambient air concentrations at the location of the SW-MEI to concentration limits set by the EPA in Table 2, Appendix E of 40 CFR 61. The radionuclides for which the comparison is made are tritium and plutonium-239+240 for the Livermore site SW-MEI and uranium-238 for the Site 300 SW-MEI. At the Livermore site, the average of the monitoring results for locations VIS and CRED represent the SW-MEI. At Site 300, the minor source that has the potential to have a measurable effect is the resuspension of depleted uranium contaminated soil. Because this is a diffuse source, the average of the results for all monitoring locations at the site are used to represent the SW-MEI.

The Table 2, Appendix E of 40 CFR 61 standards and the measured concentrations at the SW-MEI are presented in SI units in **Table 7-5**. As demonstrated by the calculation of the fraction of the standard, LLNL-measured concentrations for tritium and plutonium-239+240, and uranium-238 in air are 0.0023 or less than the health protective standard for these radionuclides.

Table 7-5. Mean concentrations of radionuclides of concern at the location of the SW-MEI in 2005

Location	Nuclide	EPA concentration standard (Bq/m^3)	Detection limit (approximate) (Bq/m^3)	Mean measured concentration (Bq/m^3)	Measured concentration as a fraction of the standard
Livermore SW-MEI	Tritium	56	0.037	$0.048^{(a)}$	8.7×10^{-4}
Livermore SW-MEI	Plutonium-239	7.4×10^{-5}	1.9×10^{-4}	$8.9 \times 10^{-9(b)}$	1.2×10^{-4}
Site 300 SW-MEI	Uranium -238	3.1×10^{-4}	1.1×10^{-4}	$7.0 \times 10^{-7(c)}$	2.3×10^{-3}

Note: 1 Bq = 2.7×10^{-11} Ci

a The tritium value includes contributions from the Tritium Facility, Building 612 Yard, DWTF Stack and Area Source, and Building 331 Waste Accumulation Area.

b The mean measured concentration for plutonium is less than the detection limit; only 3 of the 24 values comprising the mean were measured detections.

c The ratio for the mean uranium-235 and uranium-238 concentrations for 2005 is 0.005 which is less than 0.00726, the ratio of these isotopes for naturally occurring uranium. This results in approximately 57% of the resuspension being attributable to naturally occurring uranium and 43% being attributable to depleted uranium.

Estimate of Dose to Biota

Although mankind is protected from excess radiation dose by the methods outlined in this chapter, biota are not necessarily protected because of different exposure pathways (e.g., dose to a ground squirrel burrowing in contaminated soil). Thus LLNL calculates potential dose to biota from LLNL operations using the DOE guidance document, "DOE Standard: A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (U.S. DOE 2002), and the RAD-BCG (Biota Concentration Guides) Calculator

(Version 2) in an Excel spreadsheet. Limits on absorbed dose to biota are 10 mGy/d (1 rad/d) for aquatic animals and terrestrial plants, and 1 mGy/d (0.1 rad/d) for terrestrial animals. Radionuclides contributing to dose to biota were americium-241, cesium-137, tritium, plutonium-239 (analyzed as plutonium-239 and also as a surrogate for gross alpha), thorium-232, uranium-235, and uranium-238; in addition, gross beta was represented by strontium-90.

In the RAD-BCG Calculator, each radionuclide in each medium (soil, sediment, surface water) is assigned a derived concentration limit. For each concentration entered in the spreadsheet, a fraction of the derived concentration limit for that radionuclide is automatically calculated; the fractions are summed for each medium. For aquatic and riparian environments, if a concentration for water is entered, the calculator automatically assigns an expected concentration to the sediment, and vice versa.

For aquatic and riparian animals, the sum of the fractions for water exposure is added to the sum of the fractions for sediment exposure. Similarly, fractions for water and soil exposures are summed for terrestrial animals. If the sums of the fractions for the aquatic and terrestrial systems are both less than 1 (i.e., the dose to the biota does not exceed the screening limit), the site has passed the screening analysis, and biota are assumed protected.

In the LLNL assessment, the maximum concentration of each radionuclide measured in soils, sediments, and surface waters during 2005, no matter whether measured on the Livermore site, in the Livermore Valley, or at Site 300, was entered into the screening calculation. This approach will result in an assessment that is unrealistically conservative, given that the maximum concentrations in the media are scattered over a very large area, and no plant or animal could possibly be exposed to them all. Other assumptions increase the possibility that the estimated dose will be conservative. For example, while only gross alpha and gross beta are measured in water, it is assumed that gross alpha is represented by plutonium-239 and gross beta by strontium-90 to assure maximum dose. Furthermore, although biota would most likely live in and near permanent bodies of water (i.e., surface water), measurements of storm water runoff were used for the assessment because much higher concentrations of radionuclides are measured in runoff than in surface waters. Finally, when measurements were available for both runoff and sediment, the value that gave the highest fraction of the BCG was used.

In 2005, using the assumptions above, the aquatic system failed the screening test. This was due entirely to very high concentrations of gross alpha (from an upstream location) and gross beta (from a downstream location) in the runoff of February 15 at Site 300. These values were due to high levels of total suspended solids (TSS) in the runoff samples rather

than to concentrations in the runoff water, and thus they can be rejected as not representing runoff. (Suspended sediments at Site 300 contain significant quantities of naturally occurring uranium and its daughter decay products that account for elevated levels of gross alpha and beta activities.). The sum of the fractions for the aquatic system, after the highest runoff concentrations were rejected, was 0.280, and the sum for the terrestrial system was 0.035. These results for the aquatic system are similar to those in 2002, 2003, and 2004. The sum of the fractions for the terrestrial system is similar to previous years.

A less artificial assessment of dose to aquatic biota from LLNL operations can be made using runoff or release concentrations from the Drainage Retention Basin (DRB) combined with sediment concentrations from the East Settling Basin (ESB). Sediment samples are not collected in the DRB, and water is ephemeral at the ESB. Nevertheless, concentrations may be expected to be similar given that water drains through the ESB to the DRB. Using these concentrations in the RAD-BCG Calculator, the sum of the fractions for aquatic exposure is 0.034, which is about 12% of the fraction derived from the ultraconservative approach. It is clear that dose to biota from LLNL operations is below levels of regulatory concern.

Modeling Dose from Tritium — Comparison of Approaches

Dose predictions can vary due to different modeling approaches and assumptions. Because tritium has been and continues to be the principal radionuclide released to air in Livermore site operations (from a public dose standpoint), a comparison of potential doses for 2005, calculated from different approaches, is presented.

Since 1986, LLNL has calculated doses from releases of HTO (or total tritium modeled as HTO) to the atmosphere using the regulatory model CAP88-PC (since 1992) or its predecessor, AIRDOS-EPA. The dose calculated with AIRDOS-EPA or CAP88-PC uses source terms for the principal tritium sources at the site. As well, since 1979, using bulk transfer factors (**Table 7-6**) derived from equations in the Nuclear Regulatory Commission's (NRC) Regulatory Guide 1.109 (U.S. NRC 1977), LLNL has calculated potential ingestion doses from measured concentrations in vegetation (Chapter 6) and drinking water (Chapter 5), as well as doses from inhalation (Chapter 4). Both CAP88-PC and Regulatory Guide 1.109 only account for dose from HTO. More conceptually accurate assessments should account for dose from releases of HT and from ingestion of organically bound tritium (OBT); if OBT is ignored, ingestion dose may be underestimated by up to a factor of two (ATSDR 2002). In recent years, another model, NEWTRIT (Peterson and Davis 2002), has been used to estimate inhalation and ingestion doses from releases of both HT and HTO; the ingestion dose

accounts for both HTO and OBT. NEWTRIT uses observed or predicted air concentrations as input.

Table 7-6. Bulk transfer factors used to calculate inhalation and ingestion doses from measured concentrations in air, vegetation, and potential drinking water

Doses in μSv	Bulk transfer factors[a] times observed mean concentrations
Inhalation and skin absorption	0.21 x concentration in air (Bq/m^3) (See Chapter 4)
Drinking water	0.013 x concentration in drinking water (Bq/L) (See Chapter 5)
Food Ingestion	0.0049 x concentration in vegetation (Bq/kg) (See Chapter 6); (factor obtained by summing contributions of 0.0011 for vegetables, 0.0011 for meat and 0.0027 for milk)

a The derivation for these bulk transfer factors can be found in Appendix C of *Environmental Report 2002* (Sanchez et al. 2003).

Hypothetical tritium doses predicted at VIS, the on-site location of air tritium and vegetation sampling (see **Figure 4-1**), using the three modeling approaches are compared in **Table 7-7**. All predictions were made for a hypothetical person living 100% of the time adjacent to the air tritium monitor at VIS and eating 100% locally grown food. Because the air tritium monitor can only sample for HTO, only HTO releases were used to calculate air tritium concentrations using CAP88-PC.

Table 7-7. Comparison of hypothetical doses (nSv/y) at the VIS air tritium monitoring location calculated from predicted and observed concentrations of HTO in air in 2005

	CAP88-PC (from predicted air concentrations)[a]	NRC 1.109 (from mean air, vegetation, and tap water[b] concentrations)	NEWTRIT (from mean air tritium concentrations)
Inhalation and skin absorption	22	9.9	11
Food ingestion (vegetables; milk; meat)	71; 44; 26	2.6; 6.5; 2.6	28; 18; 8.9
Drinking water	1.3	< 27[c]	4.7
Food ingestion dose	141	12	54
Total dose	164	< 49	70

a Doses from CAP88-PC are based on the sum of the predicted HTO concentrations at VIS for the Tritium Facility stacks (3.70×10^{-2} Bq/m^3), the Building 612 Yard (3.48×10^{-2} Bq/m^3), and the Building 331 area source (8.14×10^{-3} Bq/m^3), the DWTF stack (1.07×10^{-3} Bq/m^3) and DWTF area source (8.14×10^{-4} Bq/m^3).

b Tap water is measured on the Livermore site but not at the VIS location.

c All tap waters measured for tritium in 2005 were below the limit of detection.

The dose comparison shows about a factor of about 3.5 between the lowest (NRC 1.109) and highest (CAP88-PC) dose predictions, each of which is based on valid assumptions. Differences are primarily due to predicted (0.0818 Bq/m^3) versus observed (0.0470 Bq/m^3) air concentrations and

assumptions about intake rates and dose coefficients (see Appendix C of *Environmental Report 2002* [Sanchez et al. 2003]). When predicted air concentrations drive the doses, doses are normally higher than when observed air and vegetation concentrations drive the results. The total dose from CAP88-PC is the highest, as expected, and the NEWTRIT dose is within a factor of 2.4 of the CAP88-PC dose.

A more realistic, but still highly conservative, set of assumptions about the lifestyle of the hypothetical member of the public residing at the VIS monitor location (**Table 7-8**) lowers the annual dose from tritium to as low as about 25% of the lowest dose in **Table 7-7**, even while including tiny potential doses from other dose pathways.

Table 7-8. Doses for the tritium exposure of an individual residing at the VIS location in 2005, based on observed HTO-in-air concentrations and using plausible but conservative assumptions (as indicated)

Source of dose	Annual dose (nSv/y)	Assumption
Inhalation and skin absorption	4.1	Breathes air at VIS 16 hours a day, all year at a lower rate than CAP88 or NEWTRIT
Ingesting food, including OBT	7.4	Raises and eats 25% homegrown leafy vegetables, fruit vegetables, fruits and root crops, no homegrown milk, beef, pork, or grain but 12 kg/y homegrown chickens and 20 kg/y homegrown eggs. Assume the feed for the chickens is 50% homegrown; chickens drink water from outdoor pans at 50% air moisture.
Drinking water	[5.9][a]	Drinks 440 L/y of well water at average concentration of California groundwater
Drinking wine, including OBT	1.6	Drinks one liter bottle of Livermore Valley wine each week at the mean concentration for 2005
All sources	13[a]	

a Drinking water dose is not included in a realistic estimate of the dose impacts of LLNL releases of tritium to the atmosphere because Livermore drinking water is unaffected by LLNL operations. Nevertheless, inclusion of a drinking water dose demonstrates that the dose attributable to LLNL is not much different than background, especially given that all doses shown include background.

Environmental Impact

The annual radiological doses from all emissions at the Livermore site and Site 300 in 2005 were found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs standard. This standard limits to 100 μSv/y (10 mrem/y) the EDE to any member of the public arising as a result of releases of radioactive material to air from DOE facilities. Using an EPA-mandated computer model and actual LLNL

meteorology appropriate to the two sites, the potential doses to the LLNL SW-MEI members of the public from operations in 2005 were:

- Livermore site: 0.065 μSv (0.0065 mrem)—41% from point-source emissions, 59% from diffuse-source emissions. The point source emissions include gaseous tritium modeled as tritiated water vapor for compliance purposes, as directed by EPA Region IX.
- Site 300: 0.18 μSv (0.018 mrem)—48% from explosive experiments, which are classified as point-sources, 52% from diffuse-source emissions.

As noted earlier, the major radionuclides accounting for the doses were tritium at the Livermore site and the three isotopes in depleted uranium (uranium-234, uranium-235, and uranium-238) at Site 300. The only significant exposure pathway contributing to dose from LLNL operations was release of radioactive material to air, leading to doses by inhalation and ingestion.

The collective EDE attributable to LLNL operations in 2005 was estimated to be 0.0117 person-Sv (1.17 person-rem) for the Livermore site and 0.0171 person-Sv (1.71 person-rem) for Site 300. These doses include potentially exposed populations of 7.1 million people for the Livermore site and 6.2 million people for Site 300 living within a distance of 80 km from the site centers.

The doses to the SW-MEI, which represent the maximum doses that could be received by members of the public resulting from Livermore site and Site 300 operations in 2005, were 0.07% and 0.18%, respectively, of the federal standard and were more than 16,000 times smaller than the dose from background radiation. The collective doses from LLNL operations in 2005 were about 700,000 times smaller than those caused by natural radioactivity in the environment.

Potential doses to aquatic and terrestrial biota from LLNL operations were assessed and found to be well below DOE screening dose limits.

In conclusion, potential radiological doses from LLNL operations were well below regulatory standards and were very small compared with doses normally received from natural background radiation sources, even though highly conservative assumptions were used in the determinations of LLNL doses. These maximum credible doses to the public indicate that LLNL's use of radionuclides had no significant impact on public health during 2005.